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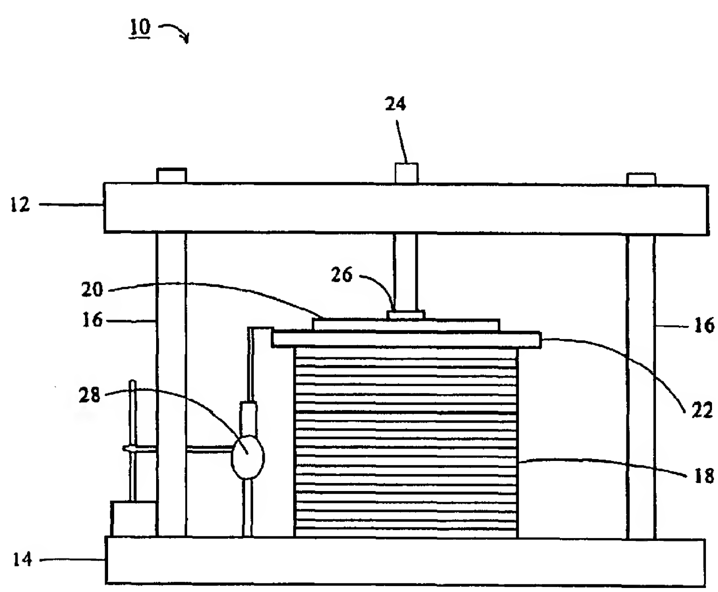
(54) **Title:** METHOD AND APPARATUS FOR MEASURING DISPLACEMENT OF A FUEL CELL STACK DURING ASSEMBLY



(57) **Abstract:** A method of testing the assembly of a fuel cell stack comprising a plurality of fuel cells (for example, solid polymer electrolyte fuel cells) applies a compressive force to the stack and measuring the displacement of the stack in response to the applied force. An apparatus for testing the assembly of a fuel cell stack comprises: (a) a compression device for applying a compressive force to the stack; (b) at least one load monitoring device for measuring the applied force; and (c) at least one displacement monitoring device for measuring the displacement of the stack in response to the applied force.

WO 02/09216 A2

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METHOD AND APPARATUS FOR MEASURING DISPLACEMENT OF A FUEL CELL STACK DURING ASSEMBLY

Field of the Invention

The present invention relates to methods and apparatus for measuring the displacement of a fuel cell stack in response to the compressive force exerted on it during assembly. The methods and apparatus are particularly useful in providing quality control during stack assembly.

Background of the Invention

Electrochemical fuel cells convert reactants, namely fuel and oxidant fluid streams, to generate electric power and reaction products. Electrochemical fuel cells employ an electrolyte disposed between two electrodes, namely a cathode and an anode. The electrodes comprise an electrocatalyst disposed at the interface between the electrolyte and the electrodes to induce the desired electrochemical reactions. The location of the electrocatalyst generally defines the electrochemically active area.

Solid polymer electrolyte fuel cells generally employ a membrane electrode assembly ("MEA") consisting of a solid polymer electrolyte or ion exchange membrane disposed between two electrode layers comprising porous, electrically conductive sheet material. The membrane is ion conductive (typically proton conductive), and also acts as a barrier for isolating the reactant streams from each other.

The MEA is typically interposed between two separator plates that are substantially impermeable to the reactant fluid streams. The plates act as current collectors and provide support for the electrodes. To control the distribution of the reactant fluid streams to the electrochemically active area, the surface of the plates that face the MEA may have open-faced channels or grooves formed therein. Such channels or grooves define a flow field area that generally corresponds to the adjacent electrochemically active area. Such separator plates, which have reactant channels formed therein, are commonly known as flow field plates. One side of a given plate may serve as an anode plate for one cell and the other side of the plate may serve as the cathode plate for the adjacent cell. In this arrangement the plates may be referred to as bipolar plates.

The fuel fluid stream that is supplied to the anode typically comprises hydrogen. For example, the fuel fluid stream may be a gas such as substantially pure hydrogen or a reformate stream containing hydrogen. Alternatively, a liquid fuel stream such as aqueous methanol may be used. The oxidant fluid stream, which is supplied to the cathode, typically comprises oxygen, such as substantially pure oxygen or an oxygen-containing air stream, for example. In a liquid feed fuel cell, a liquid oxidant stream may also be used such as, for example, an aqueous hydrogen peroxide solution.

In a fuel cell stack a plurality of fuel cells are connected together, typically in series,

to increase the overall output power of the assembly. The stack is typically held together in its assembled state by tie rods and end plates. The reactant streams are typically supplied and exhausted by respective supply and exhaust manifolds. Manifold ports are provided to fluidly connect the manifolds to the flow field area and electrodes. Manifolds and corresponding ports may also be provided for circulating a coolant fluid through interior passages within the stack to absorb heat generated by the exothermic fuel cell reactions.

Fuel cell stacks typically employ a compression mechanism to apply a compressive force on the various fuel cell components. This is desirable for a number of reasons. For example, in order to seal reactant and coolant fluid stream passages to prevent leaks or inter-mixing of the various fluid streams, fuel cell stacks typically employ resilient seals between stack components. Such seals isolate the manifolds and the electrochemically active area of the MEAs by circumscribing these areas. It is generally desirable to apply a compressive force to such seals in order to ensure adequate sealing. Compression of the stack is also desirable in order to ensure sufficient electrical contact across the surfaces of the plates and MEAs to provide the serial electrical connection among the fuel cells that make up the stack. Thus, a fuel cell stack typically needs to be properly compressed after final assembly in order for it to operate properly.

There can be hundreds of components in a fuel cell stack to be aligned and assembled for the stack to operate. The stack is then inspected to ensure proper assembly. Current component and assembly quality assurance methods are very operator dependent. It can take trained manufacturing personnel many hours to inspect an assembled stack. However, such time-intensive methods are ill suited to high-volume industrial manufacturing processes. A component and assembly quality assurance method that could be implemented in an automated assembly line with little or no supervision from a human operator would be desirable.

It is possible to measure the displacement of the stack in response to the compressive force exerted on it as a means for determining whether the stack has been properly assembled. Further, it may be possible to provide information regarding stack compression and dimensional changes in real time during actual compression in assembly. A method and apparatus for testing the assembly of a fuel cell stack during compression of the stack is described herein.

Summary of the Invention

A method of testing the assembly of a fuel cell stack comprising a plurality of fuel cells (for example, solid polymer electrolyte fuel cells) is provided, the method comprising applying a compressive force to the stack and measuring the displacement of the stack in response to the applied force. The force may be predetermined

and/or varied during the performance of the testing method, and the displacement at more than one applied force may be measured. The force may be varied incrementally during the performance of the testing method. Preferably, force and displacement are measured periodically during the performance of said testing method, and are more preferably measured continuously.

The present method may further comprise sending an output signal representative of the measured force, measured displacement, or both, to a controller. The method may also further comprise displaying the measured displacement as a function of the measured force.

The present method may further comprise comparing the displacement measured at a given force to a reference displacement for that force. Compression of the stack may be interrupted when the measured displacement varies from the reference displacement by more than a predetermined threshold amount. For example, application of the force may be interrupted in response to an output signal from the controller.

The displacement of the entire stack, or a portion thereof, may be measured in the present method. For example, the stack may be divided (notionally) into a plurality of subsections aligned in the compressive direction or in the transverse direction, and the displacement of at least one of the subsections of the stack may be measured. Where the displacement of two or more such subsections are measured at a given force, the measured displacements may be compared to a reference displacement for that force, and

compression of the stack may be interrupted when the measured displacement of at least one of the subsections differs from the reference displacement by more than a predetermined threshold amount. Alternatively, the measured displacement of each subsection at a given force may be compared with the measured displacement of the other subsections, and compression of the stack may be interrupted when the measured displacement of any of the subsections differs from each other by more than a predetermined threshold amount. For example, the stack may comprise four regions intersecting each of the four quadrants of the transverse plane of the stack, and the displacement at a given force of any two opposing regions, or all four regions, may be measured and compared as described.

The method may further comprise storing the contemporaneous data corresponding to the displacement at a given force in a database comprising statistical data corresponding to previously tested stacks, and comparing the contemporaneous data to the statistical data. The contemporaneous data may be displayed in relation to the statistical data. An alarm signal may be sent to an operator or controller when the contemporaneous data indicates that the assembly process is not in statistical control.

A method of testing the assembly of a fuel cell stack comprising a plurality of fuel cells (for example, solid polymer electrolyte fuel cells) is also provided in which the method comprises:

(a) compressing the stack, thereby displacing the stack in the compressive direction by a displacement;

(b) measuring the force exerted on the stack at that displacement; and

(c) comparing the force at that displacement to a reference force for that displacement.

Compression of said stack may be interrupted when the measured force differs from the reference force by more than a predetermined threshold amount.

An apparatus for testing the assembly of a fuel cell stack is also provided comprising:

(a) a compression device for applying a compressive force to the stack;

(b) at least one load monitoring device for measuring the applied force; and

(c) at least one displacement monitoring device for measuring the displacement of the stack in response to the applied force.

The stack may comprise a plurality of solid polymer electrolyte fuel cells and the compression device may comprise a press adapted to removably receive the stack. In this case, the press may comprise a frame comprising a base plate and a compression plate, each adapted to receive the stack, and at least one piston for urging the base plate and compression plate towards one another, thereby applying compressive force to the stack. The piston may be a pneumatic or hydraulic piston, if desired.

The load monitoring device(s) may comprise a strain gauge load cell selected from the group consisting of bending beam, shear beam, canister, ring-and-pancake, and button-and-washer load cells, more preferably a button-and-washer load cell.

The displacement monitoring device(s) may be selected from the group consisting of depth gauges, LVDTs (defined below), linear encoders, glass scale linears, linear hall effect sensors, digital probes, ultrasonic displacement sensors, and laser displacement sensors. Preferably, the displacement monitoring device is a gauging LVDT, more preferably two or four gauging LVDTs.

In the present apparatus the load monitoring device(s), displacement monitoring device(s), or both, may generate output signals representative of the measured force and/or displacement, respectively. The apparatus may further comprise a controller for receiving these output signals from the respective load and displacement monitoring devices. Additionally, the controller may further comprise a display for displaying the measured force and/or measured displacement represented by the output signals. The controller may also generate diagnostic output signals, such as an output signal representative of the displacement of the stack as a function of the force exerted thereon, and the compression device may further adjust the applied compressive force in response to the diagnostic output signals.

The controller may further generate output data representative of the measured force and measured displacement of each of a series of fuel

cell stacks, and the apparatus may further comprise a storage device for receiving and storing the output data from the controller. The apparatus may further comprise a processor for retrieving the output data from the storage device, performing statistical process control calculations employing the output data, and (optionally) displaying the results of the statistical process control calculations. The processor may be part of the controller or a separate unit.

In one embodiment of the present apparatus, the load monitoring device comprises at least one strain gauge load cell associated with a press, and the displacement monitoring device comprises at least one depth gauge associated with the press. In another embodiment, the load monitoring device comprises at least one strain gauge load cell associated with the press, and the displacement monitoring device comprises at least one gauging LVDT associated therewith. In the latter embodiment the LVDT(s) may generate output signals representative of the displacement. In either embodiment, the load cell(s) may generate output signals representative of the force, as well, and the apparatus may further comprise a controller for receiving the signals from the monitoring device(s). The controller may also comprise a display for displaying the measured force and/or measured displacement represented by the output signals.

An apparatus for compressing a fuel cell stack is also provided comprising:

(a) means for applying a compressive force to the stack;
(b) means for measuring the force exerted on the stack; and
(c) means for measuring the displacement of the stack in response to the force.

The stack may comprise a plurality of solid polymer electrolyte fuel cells. Where means for measuring the force exerted on the stack generates an output signal representative of the measured force, and/or the means for measuring the displacement of the stack in response to the force generates an output signal representative of the measured displacement, the apparatus may further comprise control means for receiving and (optionally) displaying the output signal(s).

The apparatus control means may generate diagnostic output signals, such as output signals representative of the displacement of the stack as a function of the force exerted thereon, and the means for applying the force to the stack may adjust the force in response to the diagnostic output signals. The control means may also generate output data representative of the measured force and measured displacement of each of a series of fuel cell stacks tested in the apparatus, and the apparatus may further comprise storage means for receiving and storing the output data from the control means. The apparatus may also further comprise processing means for retrieving the output data from the storage means and performing statistical process control calculations employing the output data and (optionally) displaying the results of the

statistical process control calculations. The processor may be part of the control means or a separate unit.

Brief Description of the Drawings

FIG. 1 is a schematic side view of an embodiment of the present apparatus.

FIG. 2 is a schematic side view of another embodiment of the present apparatus.

FIG. 3 is a graph of compressive force versus displacement for a Ballard Mark 10 stack.

Detailed Description of Preferred Embodiment(s)

As used in this description and in the appended claims, the compressive direction is substantially aligned with the direction of compressive force exerted on the stack (that is substantially parallel to the "stacking" direction). The transverse plane is substantially orthogonal to the compressive direction (that is substantially parallel with the major plane of the individual fuel cells in the stack). Displacement refers to the change in dimension of the fuel cell stack, or any portion thereof, in the compressive direction. LVDT means linear variable differential transducer.

There may be hundreds of components that are assembled together in a fuel cell stack. Current component and assembly quality assurance methods are time- and labor-intensive. It may take trained manufacturing personnel hours to inspect assembled stack components to ensure proper

assembly. Such methods are unsuitable for high-volume, automated manufacturing processes.

Similarly, repair or maintenance of a fuel cell stack may require disassembly of some or all of the stack components. Inspection of the re-assembled stack may also be undesirably time- and labor-intensive.

In the present method and apparatus, stack compression analysis is used to detect major faults in the assembly process and/or the stack components. Stack compression analysis involves analyzing the compressive force exerted on the stack by a compressive force in relation to the displacement of the stack due to that force. While the present method and apparatus is described in relation to solid polymer electrolyte fuel cell stacks, it is anticipated that they are likely to be applicable to stacks comprising, for example, alkaline, phosphoric acid, molten carbonate, or solid oxide fuel cells.

As the stack is being compressed, the compressive force and the resulting displacement are measured and this data may be compared to a baseline curve. Preferably, the displacement of the entire stack is measured. The baseline curve could be derived from a properly assembled stack or from a statistical analysis of many previously assembled stacks. If the stack being compressed does not compare to the baseline within a specified tolerance, then the stack is assumed to be defective and may be examined further and possibly repaired. The specified tolerance preferably takes into account expected variability in material conditions (minimum and maximum) for

the assembled stack and generally corresponds to the sum of all the individual tolerances of each of the relevant fuel cell components.

In one embodiment of the present method, the stack is compressed and the compressive force exerted on the stack to achieve a predetermined displacement is compared to a baseline force required for that same displacement. Preferably, the force exerted on the stack is varied so that the stack is compressed from a first displacement to a final displacement incrementally, and the compressive force at each of a series of incremental predetermined displacements is measured and compared to baseline compressive forces corresponding to those displacements. More preferably, displacement and compressive force are measured continuously during compression of the stack, and compared to a baseline curve.

In a preferred embodiment of the present method, the displacement of the stack obtained in response to a compressive force exerted on it is compared to a baseline displacement at that same compressive force. Preferably, the compressive force is varied. For example, the compressive force may be applied incrementally, and the displacement of the stack measured at each compressive force compared to a corresponding baseline displacement for each force. Again, more preferably, compressive force and displacement are measured continuously during compression of the stack, and compared to a baseline curve.

FIG. 1 is a schematic side view of an embodiment of the present apparatus. Compression fixture 10 comprises upper plate 12, base plate

14, and supports 16 interposed therebetween. Base plate 14 is adapted to receive fuel cell stack 18. Compression member 20 is similarly adapted to contact end plate 22 of stack 18. The surfaces of base plate 14 and compression member 20 may be substantially flat, or may have recesses, projections, or the like, for receiving stack 18. Piston 24 applies a compressive force to stack 18 via compression member 20. Load cell 26 measures the compressive force exerted on stack 18 by piston 24. Depth gauge 28 is interposed between end plate 22 and base plate 14, and measures the displacement of stack 18.

FIG. 2 is a schematic side view of another embodiment of the present apparatus. Compression fixture 30 comprises upper plate 32, base plate 34, and supports 36 interposed therebetween. Base plate 34 is adapted to receive fuel cell stack 38. Compression member 40 is similarly adapted to contact end plate 42 of stack 38. The surfaces of base plate 34 and compression member 40 may be substantially flat, or may have recesses, projections, or the like, for receiving stack 38.

Pistons 44 apply a compressive force to stack 38 via compression member 40. Load cells 46 measure the compressive force exerted on stack 38 by each of pistons 44. Locating a load cell under each piston allows for measurement of the compressive force exerted on the stack at more than one location. This arrangement may permit further analysis of the compression of the stack compared to a single force measurement, and may also provide a simple check that each of the pistons are providing the required force.

Alternatively, a single load cell may be placed under the center piston 44, for example. Such an arrangement might be appropriate where a single pneumatic or hydraulic line controls pistons 44, for example, and each piston applies the same force to the stack. If a single load cell is used in such a configuration, it is preferable to multiply the value of the force measured by the load cell by the number of pistons in order to determine the total force acting on the stack. Gauging LVDTs 48 are connected to end plate 32 and contact end plate 42 of stack 38. LVDTs 48 measure the displacement of stack 38 as it is compressed. A single LVDT 48 could be used, if desired. Alternatively, 4 LVDTs 48 could be located at different points in the transverse plane so that they measure the displacement of four quadrants (relative to the transverse plane) of stack 38. Such arrangements incorporating multiple displacement measuring devices may permit dimensional characterization of stack 38 - in particular, they may permit detection of misalignment of fuel cell components (discussed below).

Any suitable fixture for compressing the stacks can be used in the present method and apparatus. Various types of press incorporating mechanical screws, ball screws, toggle clamps, rack-and-pinion presses, or hydraulic or pneumatic pistons may be used, for example. The fixture may be manually operated or partially or fully automated. If desired, existing hardware may be fitted with the necessary instrumentation or otherwise suitably modified. The fixture should

be able to apply the necessary force to compress the stack and provide for measurement of the compressive force exerted on the stack and its corresponding displacement.

Various devices may be used in the present method and apparatus for measuring the compressive force exerted on the stack and its displacement, provided that the devices are capable of an appropriate level of accuracy and precision. For example, suitable load-measuring devices include pressure sensors such as strain gauge load cells incorporating Wheatstone bridges or piezoelectric elements. Bending beam, shear beam, canister, ring-and-pancake, or button-and-washer load cells may be suitable. Button-and-washer load cells, such as those available from OmegaDyne, Inc., (Sunbury, OH), are preferred because they are relatively small and inexpensive. Examples of suitable devices for measuring the displacement of the stack include depth gauges, LVDTs, linear encoders, glass scale linears, linear hall effect sensors, and digital probes. Gauging LVDTs, such as those available from Trans-Tek, Inc. (Ellington, CT), are a preferred type of LVDT because they do not require any permanent coupling to the stack. Other measuring devices, such as ultrasonic or laser displacement sensors, for example, may also be suitable.

Data acquisition may be manual or automated, with the latter being preferred. For example, instruments may measure the compressive force exerted on the stack and/or its displacement and send the data to a controller. The controller may comprise, for example, a programmed logic

controller ("PLC"), a computer or similar processor, or a combination of computer and PLC. The controller could then compare the data to a baseline reference. The controller may also comprise a display, such as a cathode ray tube display ("CRT") or liquid-crystal display ("LCD") display, for displaying relevant data. If the data unacceptably deviates from the accepted baseline, the controller may send an alarm signal to an operator and/or it may interrupt compression of the stack and/or may initiate some other intervening action in the assembly process. Automated data acquisition also significantly simplifies statistical process control, as discussed below.

The present method and apparatus could detect several types of defects in stack assembly or in the fuel cell components thereof. As mentioned above, each of the components of a fuel cell stack has a tolerance, resulting in an expected accumulated tolerance for the displacement of an assembled stack that accommodates minimum and maximum material conditions. Since this accumulated tolerance is generally the sum of all the individual tolerances of multiple components, the present method and apparatus may not be able to detect one small problem, such as a gap in one plate seal, for example. However, it is intended to be able to detect a significant problem or many smaller problems. For example, the present method and apparatus may be able to detect if the stack is assembled with too many or too few components. This may occur on an automated assembly line, for example, where assembly machines may occasionally

fail to pick a component or pick multiple components.

As another example, it may be possible to detect damaged components in the assembled stack. For example, plates manufactured from embossed graphite sheets may be crushed before or during compression, resulting in dimensions which are out of the expected range, and would likely affect performance of the stack. If multiple plates were crushed, the dimensional change may be sufficiently great to be detected using stack compression analysis.

As a further example, it may also be possible to detect the presence of foreign matter in the assembled fuel cell stack, provided that the foreign material prevented the proper alignment and compression of the fuel cell components.

It may also be possible to detect misalignment of components using the present method and apparatus. Misalignment may result in seals failing to align with corresponding grooves in the adjacent flow field plates. Misalignment may also result in fuel cells being offset from one another in the stack, and may significantly decrease the contact area between components. Such misalignments may significantly affect performance and sealing. Measuring the load exerted on and/or the displacement of different regions of the stack may indicate misalignment problems. For example, for a fuel cell having a rectangular cross-section, measuring and comparing the displacement at points at or near opposing transverse corners of the stack may indicate if the fuel cells are misaligned. Further, measuring

and comparing the displacement at points at or near each corner of the stack may also permit detection of the degree of parallelism between the fuel cells, as well. In the foregoing examples, compression of the stack could be interrupted when the measured parameters of any region of the stack fell outside an acceptable range, or when the difference between the measured parameters of any two regions exceeded a predetermined threshold amount. Of course, while the principle is described in relation to a stack having a rectangular cross-section, the method is also adaptable to fuel cell stacks having different cross-sectional shapes.

Similarly compression analysis may be applied to one or more subsections of the stack, such subsections layered one on top of the next (in the stacking or compressive direction). For example, the displacement of individual subgroups of fuel cells in the stack may be measured. If the displacement of such a subgroup at a particular compressive force falls outside a predetermined range, or differs from that of other comparative subgroups by more than a threshold amount, then some action may be initiated. In this way, it may be possible to locate the source of a problem within the stack, at least to within a few cells or components.

The present method and apparatus may incorporate statistical process control ("SPC"). For example, the historical force and/or displacement data for each stack that is compressed may be stored in a database and the data for a current stack could be compared with

the historical data. A computer may then generate a control chart from the data in the database to determine if the stack assembly process is out of statistical control. Suitable control charts include centering charts, dispersion charts and moving range charts, and may use single point or subgroup sampling, as appropriate. Control chart analysis incorporating simple time trends and/or rule checks can distinguish random, uncontrollable variations in measured parameters from variations that are controllable and should be corrected. Such control chart analysis can determine when a process is out of statistical control. SPC may be able to detect tool wear and/or raw product irregularities, for example. When manufacturing thousands of components there is a possibility of components being made slightly out of specification. If a tool such as a plate roller embosser, for example, is slightly out of specification due to wear, all plates made by the tool will be slightly out of their expected tolerance. Using the present method, it may be possible to detect such wear as the data for compressed stacks falls out of statistical control over time. Similarly, if raw materials are slightly out of specification, the present method may also be able to detect the problem. Other suitable SPC techniques applicable to the present method, such as capability indices, Pareto charts, fishbone diagrams, and scatter plots, for example, will be apparent to those skilled in the art.

The present method may also provide for quality assurance analysis of specific events that are expected to occur during the compression of

assembled stacks. FIG. 3 is a graph of compressive force versus displacement for a Ballard Mark 10 fuel cell stack. The curve contains at least two distinct regions of approximate linearity, which are believed to correspond to the compression of different types of components within the stack. The first region of linearity (A) is believed to correspond to the compression of the seals within the stack. The second region of linearity (B) is believed to correspond to the compression of the MEAs within the stack. By comparing the data from the compressed stack to a baseline curve such as the one shown in FIG. 3, it may be possible to determine whether the various components in the stack are not only properly aligned, but that specific events have occurred as expected during compression. Deviations from expected compression analysis values in particular regions of the curve, may give an indication of the source or nature of the problem. Similar curves for different fuel cell stack configurations may be empirically developed and used in the present method and apparatus.

Preferably, data can be collected as the stack is being compressed. Thus, stack compression analysis need not increase the assembly time of the stack and may be incorporated into an automated assembly line.

While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled

in the art, particularly in light of the foregoing teachings. It is therefore contemplated by the appended claims to cover such modifications that incorporate those features coming within the scope of the invention.

What is claimed is:

1. A method of testing the assembly of a fuel cell stack comprising a plurality of fuel cells, said method comprising:
   (a) applying a compressive force to said stack; and
   (b) measuring the displacement of said stack in response to said force.

2. The method of claim 1 wherein said fuel cells are solid polymer electrolyte fuel cells.

3. The method of claim 1 wherein said force is varied during the performance of said testing method, and the displacement at more than one applied force is measured.

4. The method of claim 1 wherein said force is varied incrementally during the performance of said testing method.

5. The method of claim 3 further comprising measuring said force and said displacement periodically during the performance of said testing method.

6. The method of claim 3 further comprising measuring said force and said displacement continuously during the performance of said testing method.

7. The method of claim 1 further comprising sending an output signal representative of said force to a controller.

8. The method of claim 1 further comprising sending an output signal representative of said displacement to a controller.

9. The method of claim 1 further comprising sending a first output signal representative of said force to a controller and sending a second output signal representative of said displacement to said controller.

10. The method of claim 9 further comprising displaying said displacement as a function of said force.

11. The method of claim 1 further comprising comparing said displacement measured at said force to a reference displacement for said force.

12. The method of claim 11 wherein application of said force is interrupted when said displacement at said force varies from said reference displacement by more than a predetermined threshold amount.

13. The method of claim 7 wherein application of said force is interrupted in response to an output signal from said controller.

14. The method of claim 1 wherein said stack comprises a plurality of subsections aligned in the compressive direction, and wherein step (b) comprises measuring the displacement of at least one of said subsections in response to said force.

15. The method of claim 14 wherein step (b) further comprises measuring the displacement of at least two of said subsections, said method further comprising comparing the measured displacement of at least one of said subsections at said force to a reference displacement for said force.

16. The method of claim 15 wherein application of said force is interrupted when said measured displacement of said at least one said subsections differs from said reference displacement by more than a predetermined threshold amount.

17. The method of claim 14 wherein step (b) further comprises measuring the displacement of at least two of said subsections, said method further comprising comparing the displacement of said subsections at said force with each other, and interrupting application of said force when the measured displacement of any of said subsections differs from the measured displacement of any other of said subsections by more than a predetermined threshold amount.

18. The method of claim 1 wherein said stack comprises a plurality of regions aligned in the

transverse direction, and wherein step (b) comprises measuring the displacement of at least one of said subsections in response to said force.

19. The method of claim 18 wherein step (b) further comprises measuring the displacement of at least two of said subsections, said method further comprising comparing the measured displacement of at least one of said subsections at said force to a reference displacement for said force.

20. The method of claim 19 wherein application of said force is interrupted when said measured displacement of said at least one of said subsections differs from said reference displacement by more than a predetermined threshold amount.

21. The method of claim 18 wherein step (b) further comprises measuring the displacement of at least two of said subsections, said method further comprising comparing the displacement of said subsections at said force with each other, and interrupting application of said force when the measured displacement of any of said subsections differs from the measured displacement of any other of said subsections by more than a predetermined threshold amount.

22. The method of claim 1 wherein said stack further comprises four regions intersecting each of the four quadrants of the transverse plane of said stack, and wherein step (b) further comprises

measuring the displacement at said force of any two opposing said regions.

23. The method of claim 1 wherein said stack further comprises four regions intersecting each of the four quadrants of the transverse plane of said stack, and wherein step (b) further comprises measuring the displacement at said force of each of said regions.

24. The method of claim 1 further comprising:

storing the contemporaneous data corresponding to said displacement at said force in a database comprising statistical data corresponding to previously tested stacks; and

comparing said contemporaneous data to said statistical data.

25. The method of claim 24 further comprising displaying said contemporaneous data in relation to said statistical data.

26. The method of claim 24 wherein an alarm signal is sent to an operator or controller when said contemporaneous data indicates that the assembly process is not in statistical control.

27. A method of testing the assembly of a fuel cell stack comprising a plurality of fuel cells, said method comprising:

(a) compressing said stack, thereby displacing said stack in the compressive direction by a displacement; and

(b) measuring the force exerted on said stack at said displacement; and

(c) comparing said force at said displacement to a reference force for said displacement.

28. The method of claim 27 wherein compression of said stack is interrupted when said measured force differs from said reference force by more than a predetermined threshold amount.

29. An apparatus for testing the assembly of a fuel cell stack, said apparatus comprising:

(a) a compression device for applying a compressive force to said stack;

(b) at least one load monitoring device for measuring said force; and

(c) at least one displacement monitoring device for measuring the displacement of said stack in response to said force.

30. The apparatus of claim 29 wherein said stack comprises a plurality of solid polymer electrolyte fuel cells.

31. The apparatus of claim 29 wherein said compression device comprises a press adapted to removably receive said stack, said press comprising:

(1) a frame comprising a base plate and a compression plate, each adapted to receive said stack; and

(2) at least one piston for urging said base plate and compression plate towards one

another, thereby applying compressive force to said stack.

32. The apparatus of claim 31 wherein said at least one piston is a pneumatic piston.

33. The apparatus of claim 31 wherein said at least one piston is a hydraulic piston.

34. The apparatus of claim 29 wherein said at least one load monitoring device is a strain gauge load cell selected from the group consisting of bending beam, shear beam, canister, ring-and-pancake, and button-and-washer load cells.

35. The apparatus of claim 34 wherein said load cell is a button-and-washer load cell.

36. The apparatus of claim 29 wherein said at least one displacement monitoring device is selected from the group consisting of depth gauges, LVDTs, linear encoders, glass scale linears, linear hall effect sensors, digital probes, ultrasonic displacement sensors, and laser displacement sensors.

37. The apparatus of claim 29 wherein said at least one displacement monitoring device is an LVDT.

38. The apparatus of claim 29 wherein said LVDT is a gauging LVDT.

39. The apparatus of claim 29 wherein said at least one displacement monitoring device comprises two LVDTs.

40. The apparatus of claim 29 wherein said at least one displacement monitoring device comprises four gauging LVDTs.

41. The apparatus of claim 29 wherein said at least one load monitoring device generates an output signal representative of said measured force, and

said at least one displacement monitoring device generates an output signal representative of said measured displacement,

said apparatus further comprising:

(d) a controller for receiving said output signals from the respective load monitoring and displacement monitoring devices.

42. The apparatus of claim 41 wherein said controller further comprises a display for displaying said measured force and said measured displacement represented by said signals.

43. The apparatus of claim 41 wherein said controller generates diagnostic output signals representative of the displacement of said stack as a function of said force exerted thereon, and said compression device adjusts said applied compressive force in response to said diagnostic output signals.

44. The apparatus of claim 41 wherein said controller generates output data representative of said measured force and said measured displacement of each of a series of fuel cell stacks, said apparatus further comprising a storage device for receiving and storing said output data from said controller.

45. The apparatus of claim 44 further comprising a processor for retrieving said output data from said storage device and performing statistical process control calculations employing said output data.

46. The apparatus of claim 45 wherein said processor further comprises a display for displaying the results of said statistical process control calculations.

47. The apparatus of claim 45 wherein said controller and said processor are the same unit.

48. The apparatus of claim 30 wherein said load monitoring device comprises at least one strain gauge load cell associated with said press, and said displacement monitoring device comprises at least one depth gauge associated with said press.

49. The apparatus of claim 30 wherein said load monitoring device comprises at least one strain gauge load cell associated with said press, and said displacement monitoring device comprises

at least one gauging LVDT associated with said press.

50. The apparatus of claim 49 wherein said at least one load cell generates output signals representative of said force, and said at least one LVDT generates output signals representative of said displacement, the apparatus further comprising: a controller for receiving said signals from said at least one load cell and said at least one LVDT.

51. The apparatus of claim 50 wherein said controller further comprises a display for displaying said measured force and said measured displacement represented by said signals.

52. The apparatus of claim 50 wherein said controller generates diagnostic output signals representative of the displacement of said stack as a function of the force exerted thereon, and said press adjusts said force in response to said diagnostic output signals.

53. The apparatus of claim 50 wherein said controller generates output data representative of said measured force and said measured displacement of each of a series of fuel cell stacks, said apparatus further comprising a storage device for receiving and storing said output data from said controller.

54. The apparatus of claim 53 further comprising a processor for retrieving said output

data from said controller and performing statistical process control calculations employing said output data.

55. The apparatus of claim 53 wherein said processor further comprises a display for displaying the results of said statistical process control calculations.

56. The apparatus of claim 53 wherein said controller and said processor are the same.

57. An apparatus for compressing a fuel cell stack, said apparatus comprising:

(a) means for applying a compressive force to said stack;

(b) means for measuring the force exerted on said stack; and

(c) means for measuring the displacement of said stack in response to said force.

58. The apparatus of claim 57 wherein said stack comprises a plurality of solid polymer electrolyte fuel cells.

59. The apparatus of claim 57 wherein said means for measuring the force exerted on said stack generates an output signal representative of the measured force, and

said means for measuring the displacement of said stack in response to said force generates an output signal representative of the measured displacement, the apparatus further comprising:

(d) control means for receiving each of said output signals.

60. The apparatus of claim 59 further comprising means for displaying said measured force and said measured displacement represented by said output signals.

61. The apparatus of claim 59 wherein said control means generates diagnostic output signals representative of the displacement of said stack as a function of the force exerted thereon, and said means for applying said force to said stack adjusts said force in response to said output signals.

62. The apparatus of claim 59 wherein said control means generates output data representative of said measured force and said measured displacement of each of a series of fuel cell stacks tested in said apparatus, said apparatus further comprising storage means for receiving and storing said output data from said control means.

63. The apparatus of claim 59 further comprising processing means for retrieving said output data from said storage means and performing statistical process control calculations employing said output data.

64. The apparatus of claim 63 further comprising means for displaying the results of said statistical process control calculations.

65. The apparatus of claim 63 wherein said control means and said processing means are the same unit.

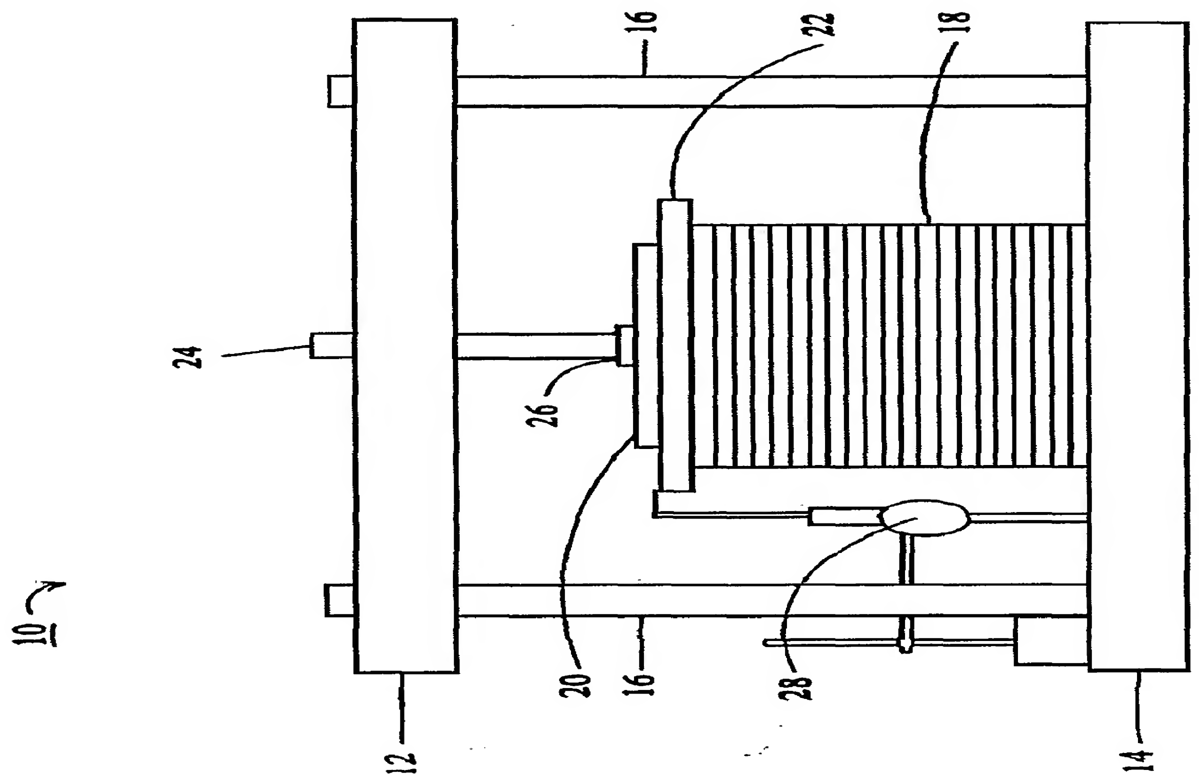


Fig. 1

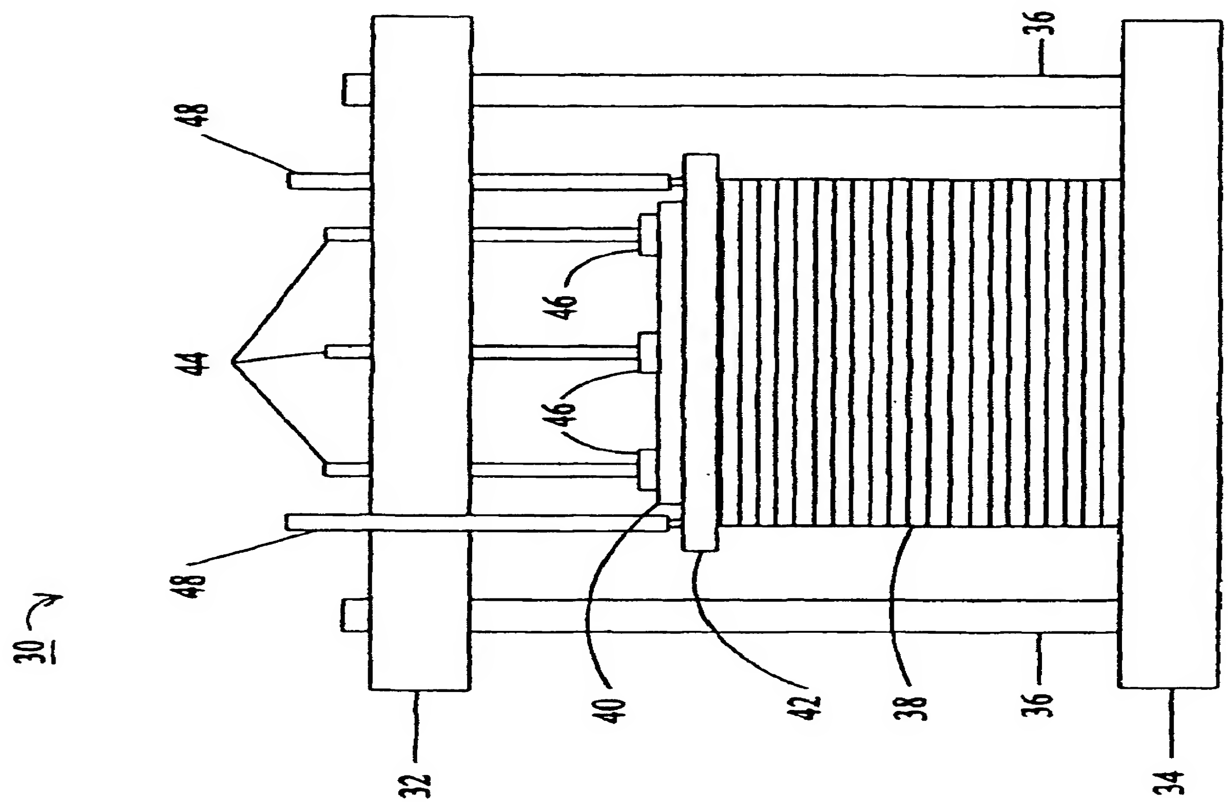
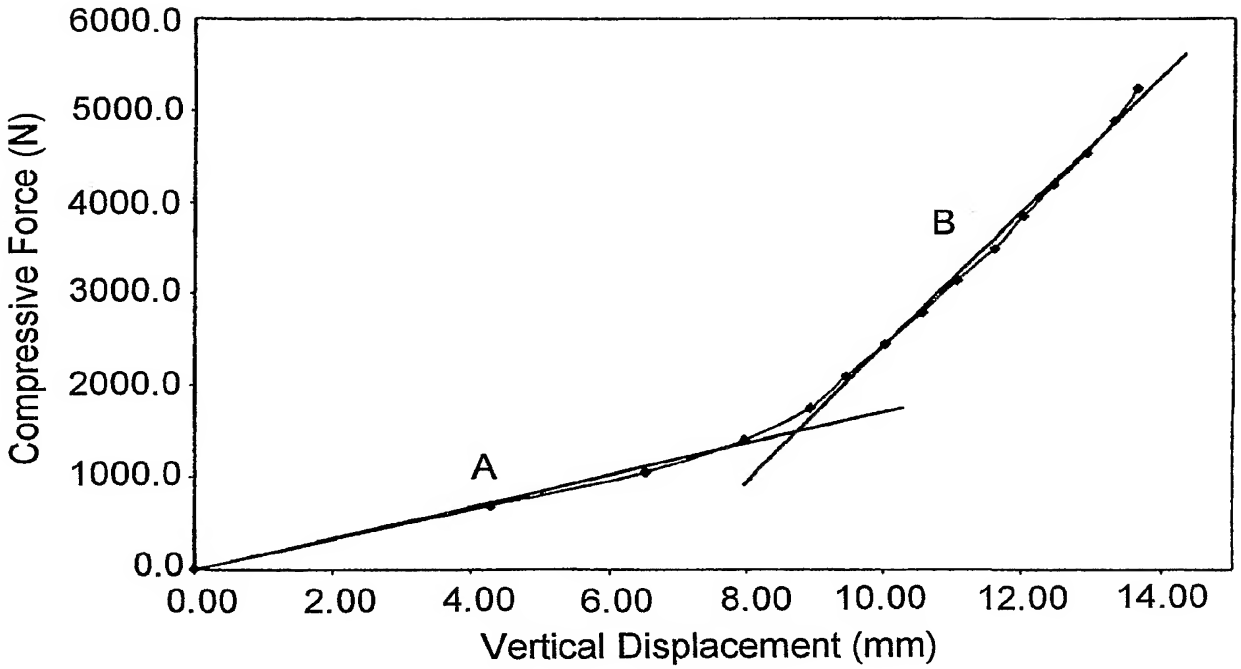


Fig. 2

Fig. 3


6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Compressive Force (N)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Vertical Displacement (mm)
A
B